



Goal Provenance for Collaborative Autonomy

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Research Funded by ONR and NRL.

NATO SCI-335: Autonomy from a System Perspective – Version 2.0

Panel: Optimizing the Human-Machine Resource Allocation for the Future Force

24-26 May 2021

Goal Provenance

What is the **provenance** of a goal
– its supporting data and commitments –
that got us to now?

Managing Goals

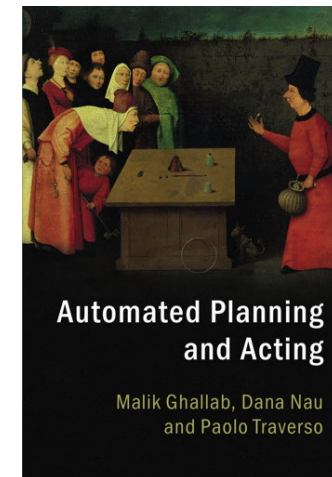
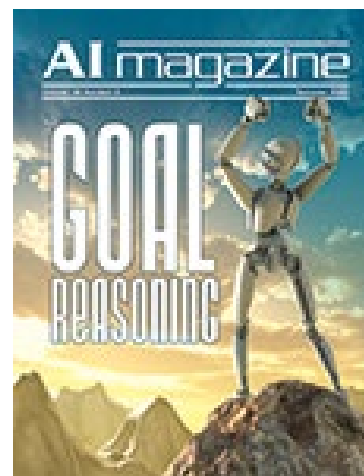
Deliberating about Goals

Deliberating *during Execution*

Plans are meant to be executed!

Aha, D. W. (2018). **Goal Reasoning: Foundations, Emerging Applications, and Prospects.** *AI Magazine*, 39(2), 3-24.

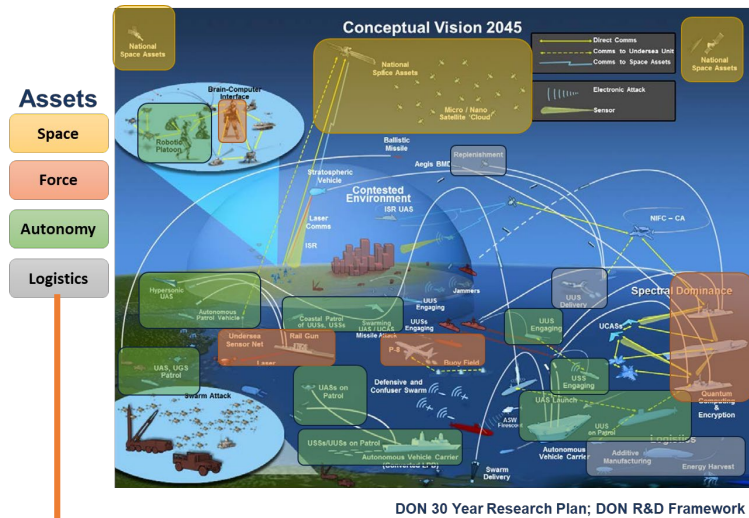
<https://doi.org/10.1609/aimag.v39i2.2800>



Ghallab, Nau, & Traverso. (2016) ***Automated Planning and Acting***. Cambridge Univ. Press. Authors' Manuscript Freely Downloadable <http://projects.laas.fr/planning/>

Motivation: 2045 Theatre

Track evolving goals of mixed teams of humans, robots and software



- Complex goals span the theatre
- Require unified perspective of individual or shared goals as scenario unfolds

AACUS Autonomous Logistics Vehicle

https://www.youtube.com/watch?v=NZv3W9q4_FA



AACUS



CDR

Current Techniques / Our Approach

Track evolving goals of mixed teams of humans, robots and software

Hierarchical Networks:

Leverage domain knowledge

Fast planning

Costly to “Program”

Granular Abstraction

(Deep) RL Policies:

Flexible, reward driven

Fast execution (once trained)

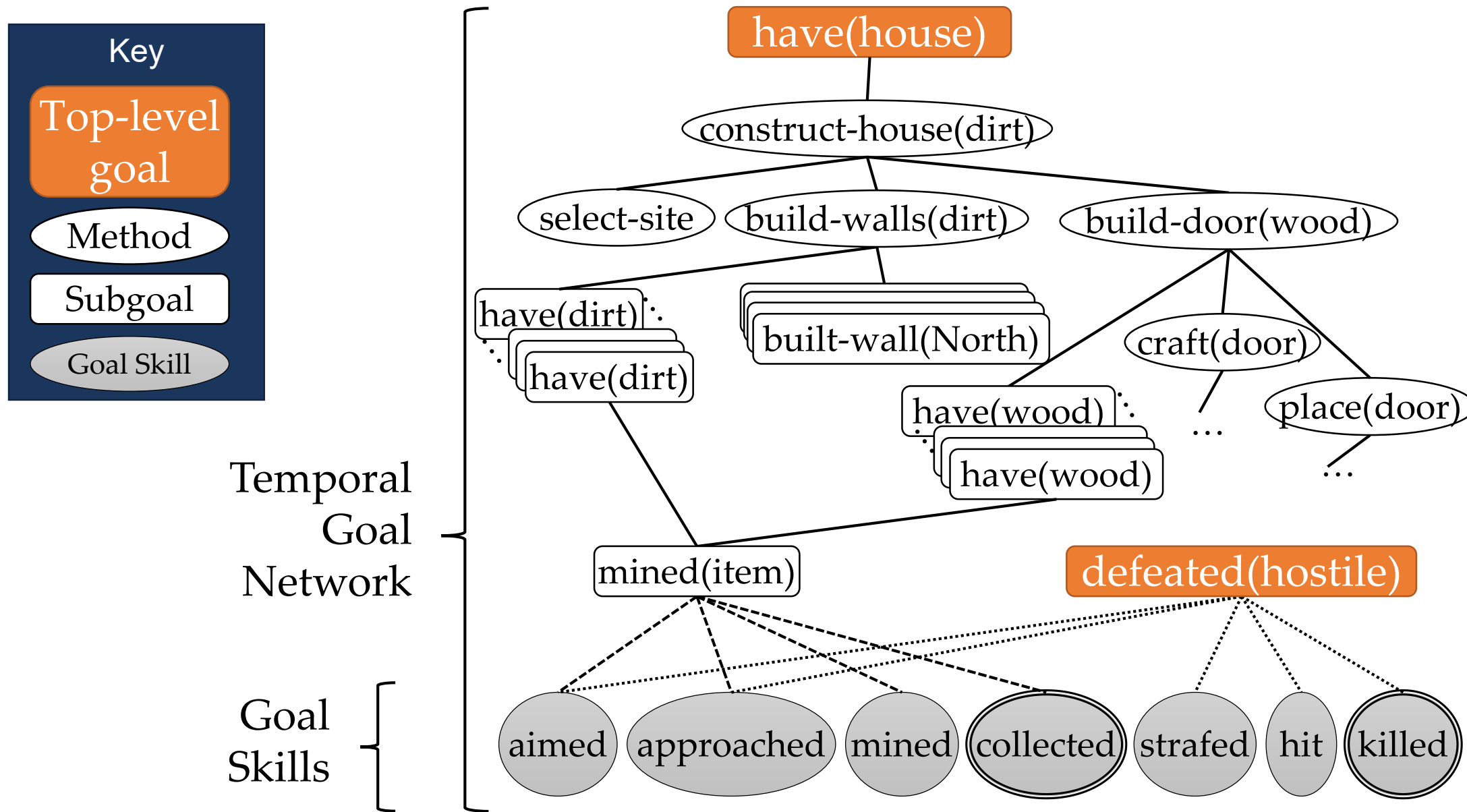
Costly to train

Limited horizon and sharing

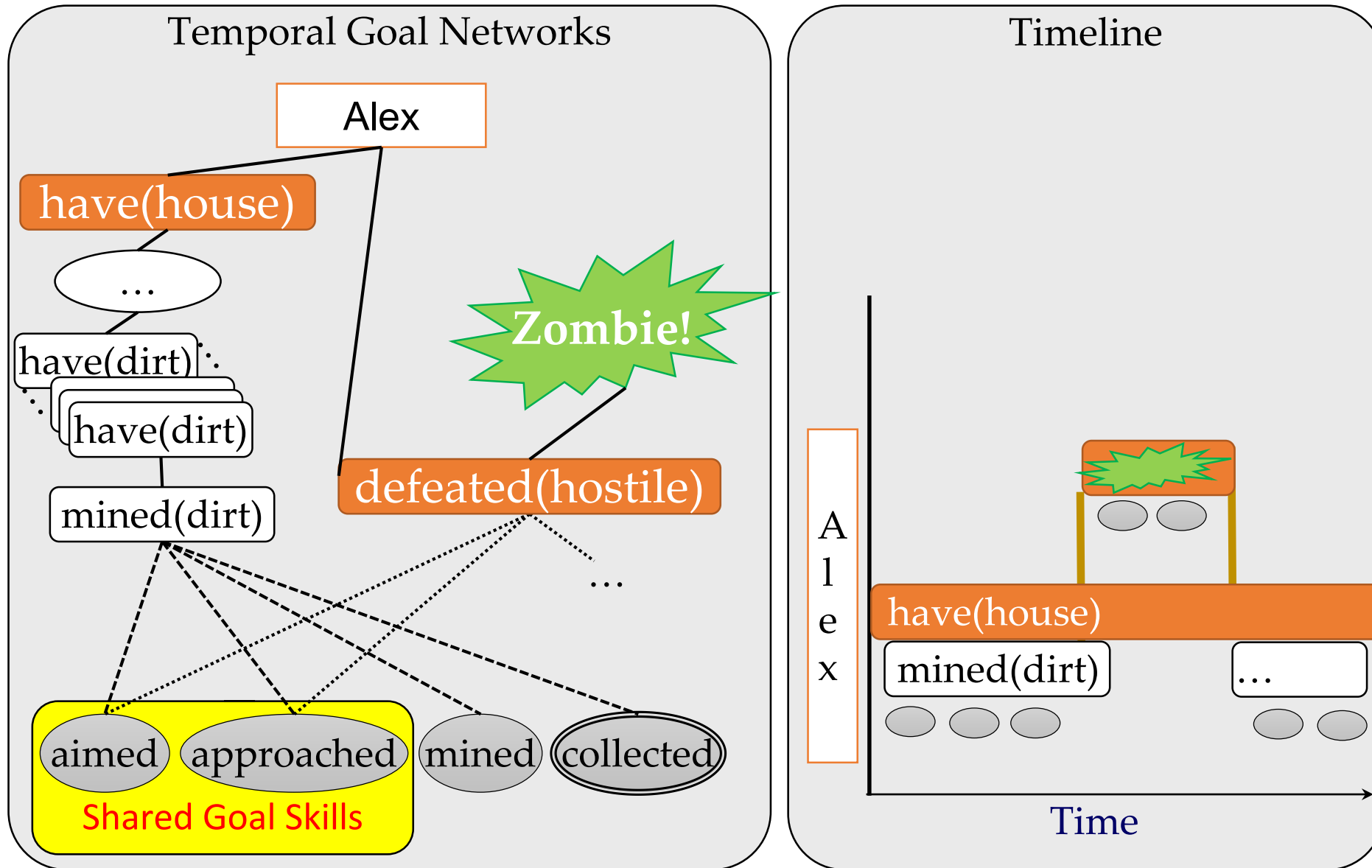
Temporal Goal Networks (TGNs):

- Track past/future commitments
- Link RL skills to goal network leaves
- Develop online algorithms
- Learn skills & hierarchies from traces

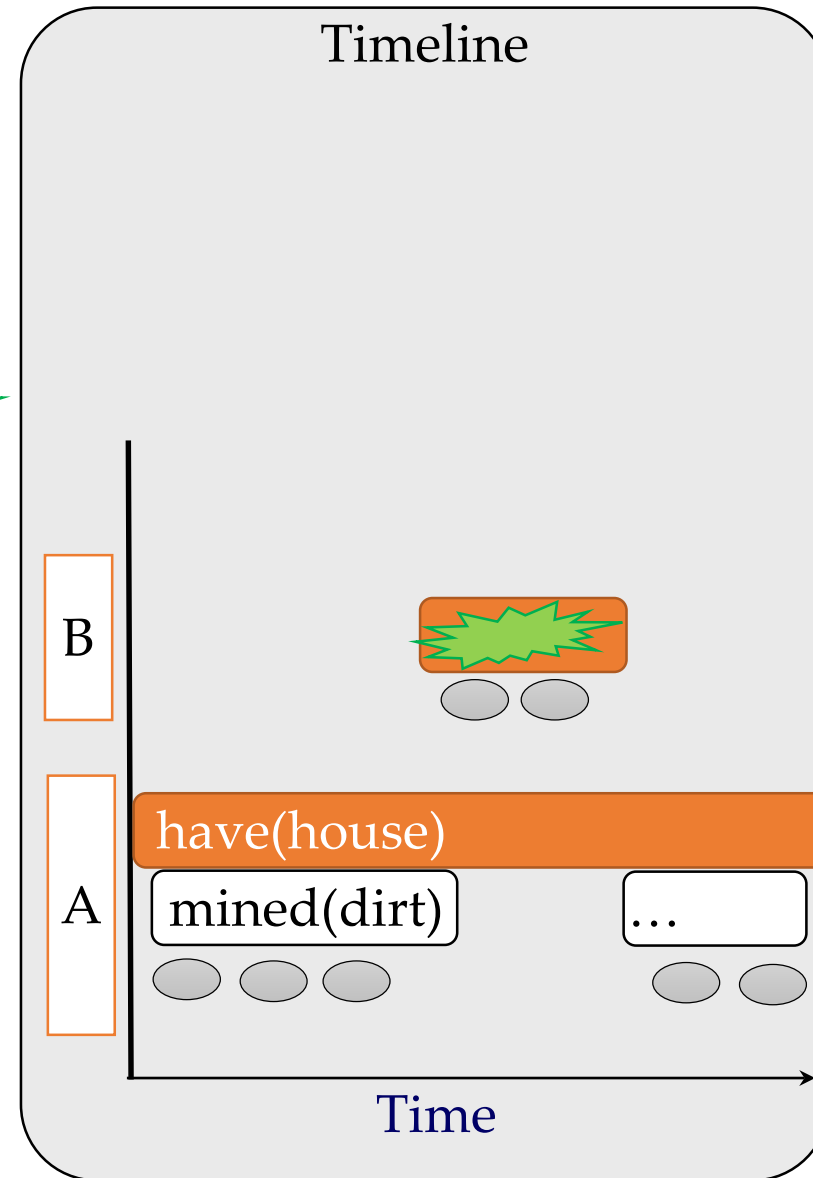
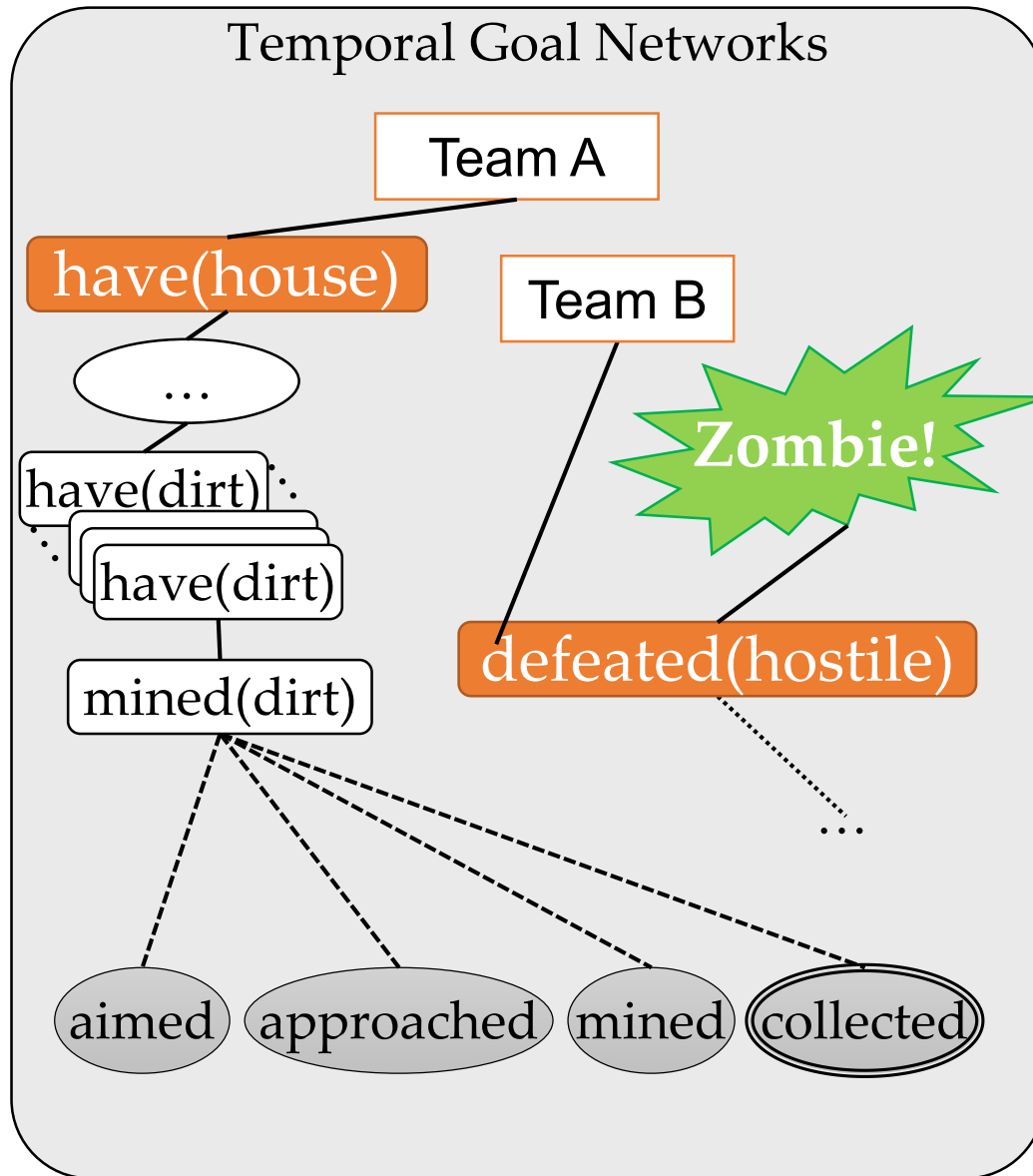
Example Temporal Goal Network



Single-Agent TGN with Timeline



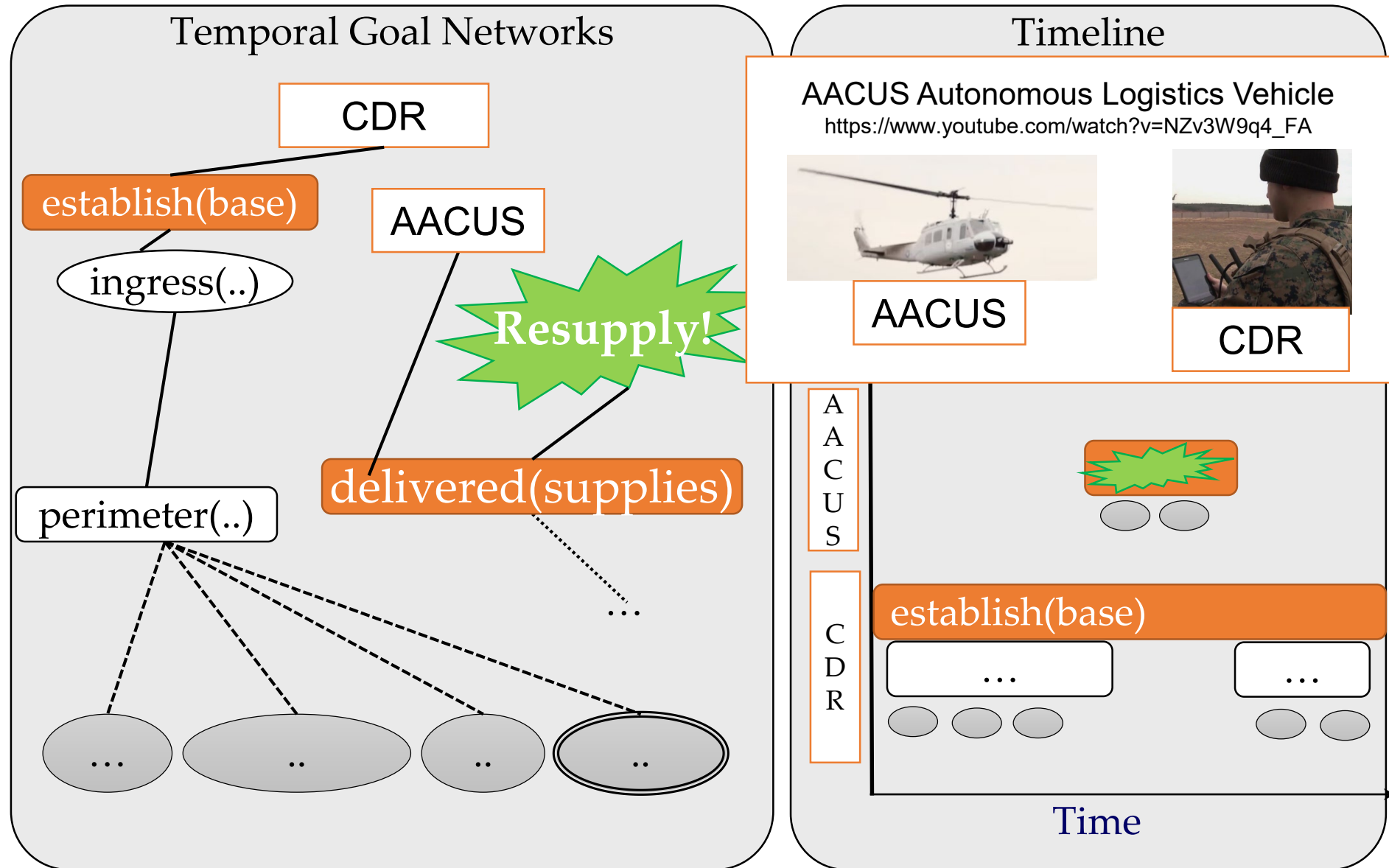
Multi-agent TGN with Timeline



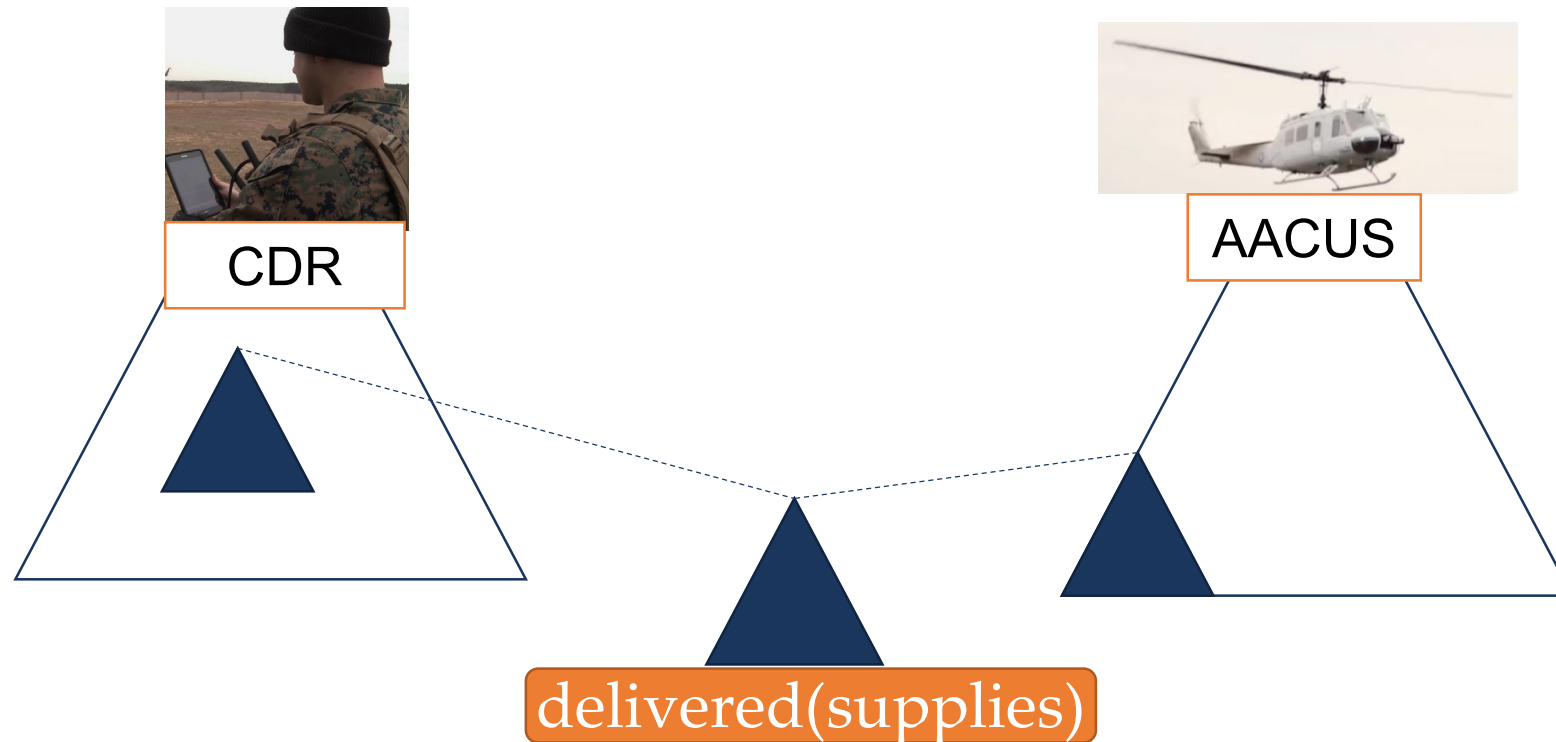
Key

- Top-level goal
- Method
- Subgoal
- Goal Skill

Navy-Relevant TGN with Timeline



Goal Sharing Example



Limitations of existing theory:

- Incomplete operational semantics
- Too hard to solve

We will find tractable subclasses that are:

- Navy relevant
- Can be solved quickly

Temporal Goal Network

Network

Collection of objects:

- Edges relate objects
- May be ordered

Goal

An objective that is:

- Achieved
- Maintained

Goal Lifecycle

- Goal Reasoning
- Execution focused
- Cognitive Cycle

Temporal

- Temporal Constraints
- Deadlines
- Resource Dependency

Goal Network*

- Collection of goals
- Edges relate goals
 - Subgoals
- Partially ordered

Goal Lifecycle Network[†]

- Goal Network with:
 - Goal Lifecycle
 - Execution Lifecycle
- Three robotic simulation demos

Temporal Goal Network[‡]

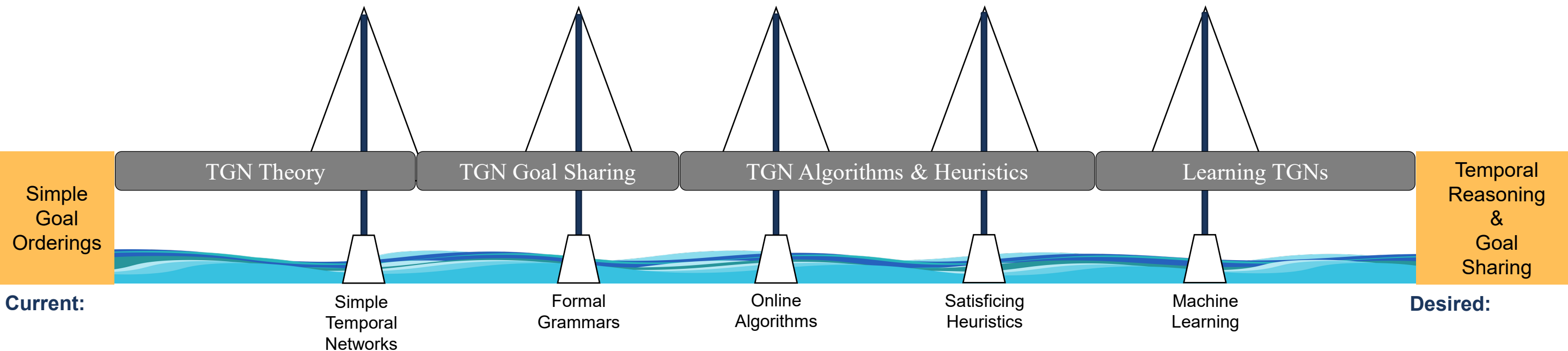
- Goal Network with:
 - Sharing semantics
 - Online algorithms
 - Linkage to “behaviors”

* Shivashankar, V. **Hierarchical Goal Network Planning: Formalisms and Algorithms for Planning and Acting.** Department of Comp. Sci., Univ. Maryland C.P., May 2015.

[†] Upcoming publications

[‡] Where we want to be

Bridging the Gap



Existing Goal Networks

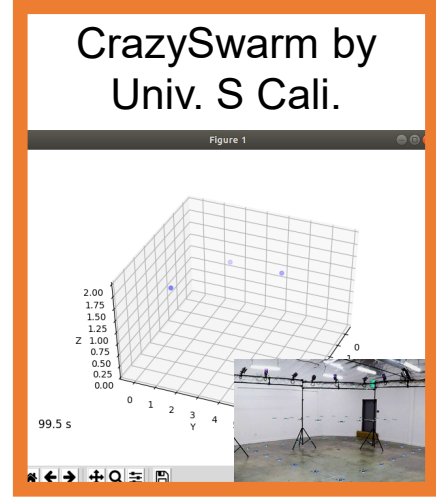
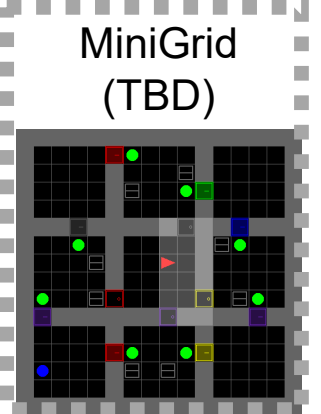
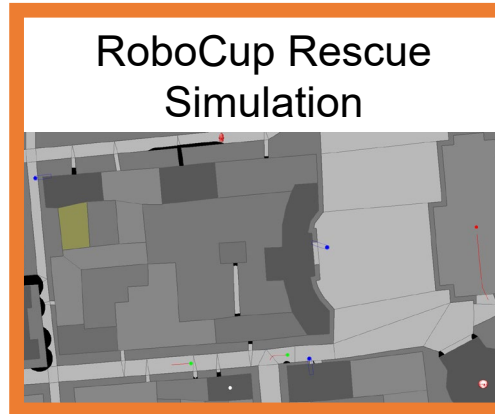
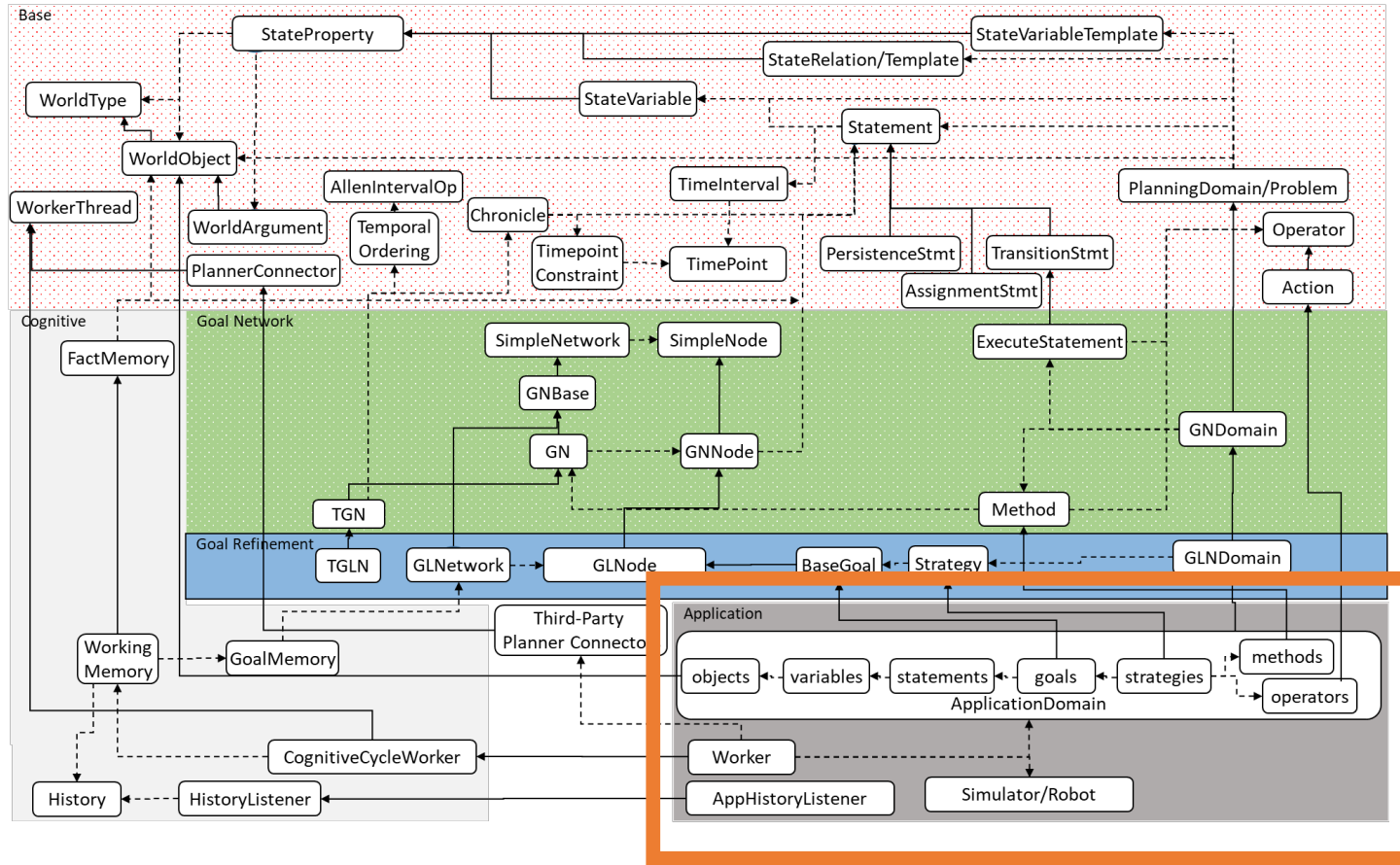
- L1: lack temporal theory
- L2: lack goal sharing
- L3: use offline algorithms
- L4: not tested at scale

Temporal Goal Networks

- S1: create temporal theory
- S2: develop goal sharing
- S3: build online algorithms
- S4: learn TGNs from traces

ActorSim: A Reference Implementation of Goal Lifecycle Networks

ActorSim Component Diagram (v2020.05)



Collaborators and Foundations

Naval Research Laboratory

David W. Aha – Branch Head

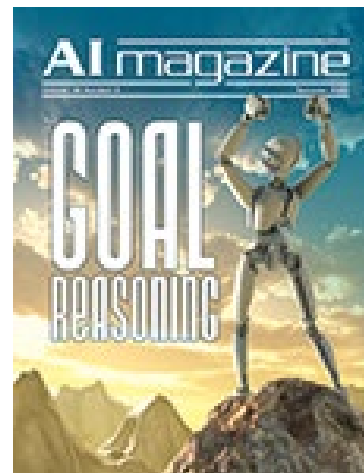
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Tool Jampathom
Vivint Shetty

NRL Contractors

Bryan Auslander* – Knexus Research
Vikas Shivashankar* (now at Amazon Robotics)
Darin King – Expert Methods, Inc.
Bart Posselt – System Definition, Inc.

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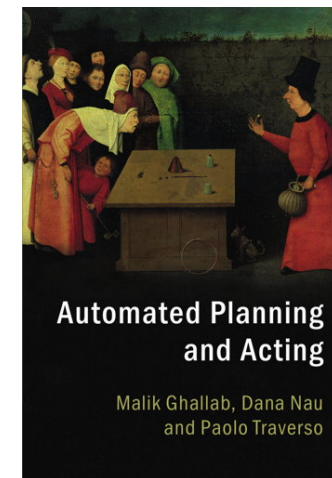
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Visiting or Funded Faculty

Prof. Briana Wellman* - *University of DC*
Prof. Dongkyu Choi* - *Kansas University*
Prof. Darrell Whitley – *Colorado State University*
Prof. Dana Nau – *University of Maryland*

Postdocs

Swaroop Vattam* (now at Lincoln Labs, MIT)
Ronald Alford* (now at MITRE)
Ben Johnson* (now at Honeywell)
Dustin Dannenhauer* (now at WSRI)
Sunandita Petra – *University of Maryland*



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Authors' Manuscript Freely Downloadable
<http://projects.laas.fr/planning/>

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Visiting Students

Shubham Gupta* - *TJ High School*
Michael Leece* - *University of California, Santa Cruz*
Pryce Bevan* - *Georgetown University*
David Menager* - *Kansas University*
David Isele* - *University of Pennsylvania*
Alison Parades - *University of New Hampshire*
Rey Pocius - *Oregon State University*
Jared Okun* - *Rensselaer Polytechnic Institute*
Elana Trafton – *James Madison University*
Sachini Weerawardhana* - *Colorado State University*
Pavan Kantharaju* - *Drexel University*
Irina Rabkina – *Northwestern University*
Mark Cavolosky – *University of Maryland*
Ruoxi Li – *University of Maryland*
Alex Mendelsohn – *University of Maryland*
Onur Kulaksizoglu – *University of Maryland*

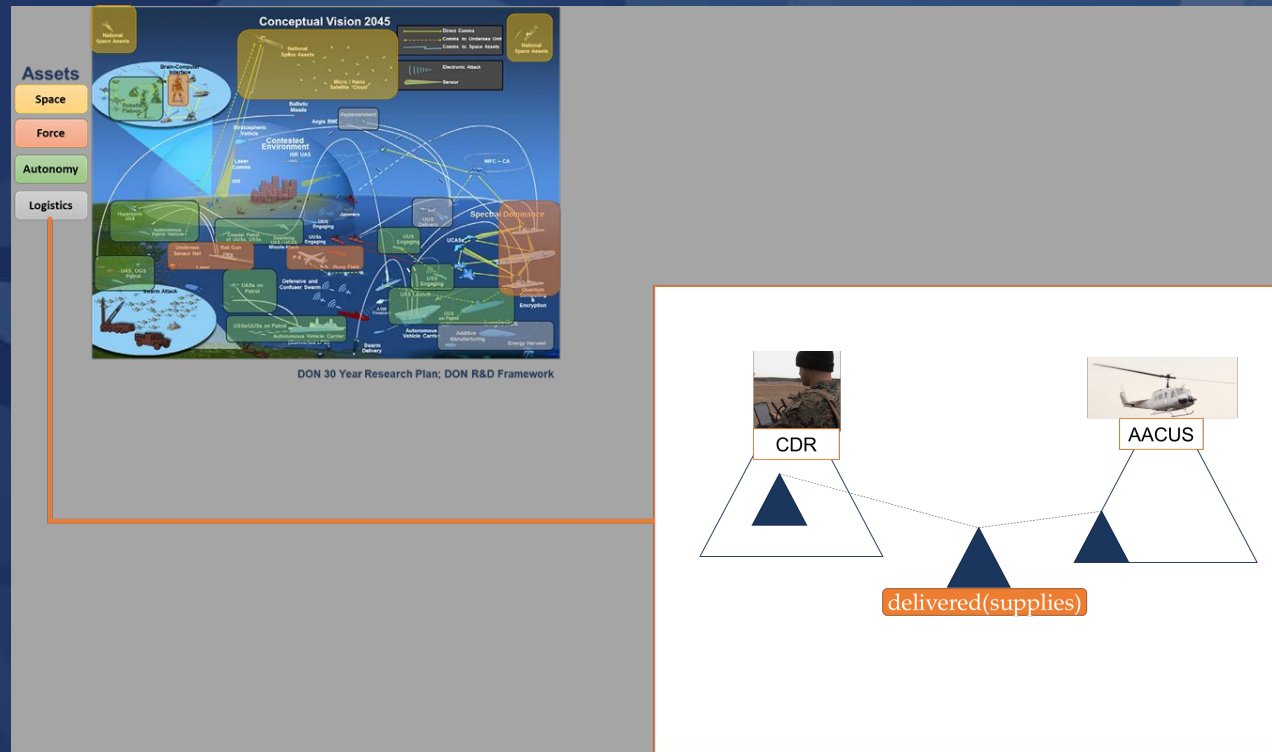
Current collaboration *hired or funded by David Aha!

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Example Goal Skill

